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On the Influence of the Liquid Type on Mobile Phone Measurements Using Body Phantoms

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Abstract

The evaluation of mobile handset performance with respect to received and transmitted power needs to be carried out in realistic environments, including both the mobile radio channel and the handset user. Using phantoms mimicking the human body is an attractive way to avoid the time consuming measurements with the many test persons otherwise necessary. This paper investigates the difference in link loss for various choices of the tissue simulating liquid often used inside phantoms of the human body. Three liquid types have been tested in both a full body phantom useful for testing body carried devices, and in a head/hand phantom. The investigation is based on a series of measurements made in a live GSM network involving four common handset types. In addition, the three liquids were also tested by anechoic chamber measurements of the handsets including a phantom.

1. Introduction

An important issue in the design of a mobile handset is the antenna, or the radiating elements. A poorly performing antenna can lead to increased power consumption and reduced coverage, and the network as a whole will loose capacity if many handsets have poor instead of high performance antennas.

It is widely recognized that due to the complicated propagation environment of the antenna, the handset antenna performance needs to be evaluated in realistic scenarios, where all important issues are included [1–3].

For the case of handheld mobiles it has been demonstrated previously that the performance in terms of received and transmitted power is highly dependent on the user, where differences from user to user up to 10 dB have been found [4, 5]. The so-called body loss describes the difference (in dB) in received power when the user is present and when no user is present. The body loss varies not only from user to user but the mean body loss also varies from handset to handset, depending on the design [6]. Because of the variation in the body loss among different users it is necessary to measure the body loss with many users (say, at least 10) in order to obtain accurate results [7]. Obviously this is a disadvantage for extensive testing and for this and other reasons the use of phantoms mimicking the real user has been considered.

In order to be useful, the body loss obtained with a phantom must match the average body loss obtained with real users [8]. An investigation of this has been the purpose of a large measurement campaign in which the performance of different handsets was measured both for a large number of test users as well as for two different standardized phantoms. The performance of the handsets were tested in a live GSM network using the technique of Abis logging. In this way the actual GSM network becomes the measurement system and the performance evaluation can be done when the handset is in normal use.

Both of the tested phantoms are filled with a liquid simulating the human tissue in the sense that the electrical properties of the liquid are similar to that of human tissue. The properties of the liquids are frequency dependent, and therefore they are designed to be used at specific frequency bands, such as 900 MHz and 1800 MHz for the GSM system. It is customary to use phantoms for specific absorption rate (SAR) measurements where the issue of liquid type is highly important. However, for performance evaluations such as body loss measurements the influence of the liquid type is unknown.

The body loss measurement is different from the SAR measurement in that the SAR is the power absorbed in a specified mass of the tissue, typically 1 g or 10 g, whereas the body loss is the power loss in the full body of the user. The distribution of the power absorption inside the user is not important for the body loss value whereas the peak SAR values may change with the distribution.

The current paper focus on the influence of the liquid on the body loss, and in particular the differences observed when the phantoms are filled with different types of liquids.

2. Measurements

In a GSM network the *Abis* interface is the interface between the base transceiver station (BTS) and the base station controller (BSC). Most of the control information transferred between the network and the mobile station passes the Abis, in particular the measurement reports (MRs). The MRs contain, among other information, the RxLev measurements, which is a measure of the received power level. A MR is transferred at least once per second, and usually about twice per second. The measurements used in this work utilizes the information given in the MRs to characterize the observed channel.

The measurement campaign was based on logging the information transferred on the Abis interface of a live GSM network in cooperation with TeleDanmark, a Danish GSM network operator. During the logging all frames on the Abis were stored for later processing. The logging and post processing of the Abis frames are described in [6]. This paper describes in detail another measurement campaign carried out in the same environment, as used in the current campaign.

The measurements were carried out in a building at Aalborg University where a microcell base station is located approximately 75 m away. The base station carries both GSM-900 and GSM-1800 cells, and data from both frequency bands are used. The measurement building is situated in the outskirts of the city and is a new four story office building mainly made of reinforced concrete with an outer brick-wall. The measurements took place in corridors of the basement and the 2nd floor, where the basement corridor has walls of concrete and only a few windows and doors. The 2nd floor is an office floor with many windows towards the base station and most inner walls made of plaster board.

The campaign included measurements with live test users for both the handheld and the body carried case, and in addition two phantoms were used. The current paper focus on the measurements involving the two phantoms.

The first phantom is the so-called full body phantom (FBP) which is specified by ETSI [9]. This phantom consists of a 2 m high acrylic tube with a diameter of 30 cm. Inside this cylinder is another similar tube with a diameter of 20 cm, and the two tubes are connected and fixed at the top and bottom. The volume between the two tubes is filled with a liquid simulating the human tissue (see below). The FBP was put on a low trolley with a string attached, allowing the FBP to be pulled, see Figure 1.

During the measurements the handsets were mounted on the FBP using thin office tape in the following three positions. α: 145 cm above floor, with the phone front away from the FBP and in the direction of motion. β: 105 cm above floor, with the phone front away from the FBP on the right side with respect to the direction of motion. γ: similar to α, but with the phone front towards

Figure 1: The FBP in the 2nd floor corridor.

the FBP. These positions were chosen to mimic the situation where a person is using a handsfree kit and carry the handset on the body in either the chest or hip pocket.

The second phantom mimics the human head and upper parts of the chest/shoulders. This phantom is sold by Schmid & Partners [10] and is a hollow fiber-glass construction which is filled with a tissue simulating liquid. For the measurements a phantom hand was added, which is a rubber glove filled with the same type of liquid as the head phantom. Henceforth this is referred to as the head and hand phantom (HHP), see Figure 2. The phantom hand is attached to the head and during a measurement the handset is fixed between the hand and the head, as for a human holding the handset to the ear using the left hand. Two positions of the hand are used; In the α-position the side of the hand is located approximately 5 cm below the ear-piece of the handset. For the β-position the hand is similarly located approximately 1 cm below the ear-piece.

Four handsets were used which are commercially available and represents the most important handset types used today. Handset A and B are large handsets with external and internal antennas, respectively. Handset C and D are small handsets with internal and external antennas, respectively. Here 'small' handsets are among the smallest handsets available today, about 10 cm by 4.5 cm, and the 'large' handsets are about 13 cm by 4.5 cm.

Measurements were made for all combinations of the four handsets, the 2 and 3 positions on the two phantoms, and the two levels of the building. Furthermore, each measurement was repeated 4 or 5 times and for each type of phantom two liquids were tested, see below. The measurements were carried out in as much the same way as possible, described below for the HHP case.

Each measurement starts at the south end of the corridor where the person performing the measurement makes

Figure 2: One of the handsets mounted for measurements with the HHP.

a call and waits for connection. When the call is established the handset is mounted between the phantom head and the hand, after which the trolley with the phantom is pushed slowly down the middle of the corridor. Upon reaching the far end of the corridor, the table is turned around and returned in the same way. Reaching the starting point, the handset is dismounted and the call is ended.

The time instants for the beginning and ending of the walk down the corridor were noted down to make it possible afterwards to discard the parts of the call in which the handset was mounted and dismounted. To avoid activation of discontinuous transmission (DTX) in the downlink (DL) direction the measurements were made by calling an answering machine on which some music was recorded. For the up-link (UL), a portable CD player was connected to a small loudspeaker close to the handset microphone.

In total three tissue simulating liquids were used, a salt/water solution and a SAR liquid, the latter both in a 900 MHz and a 1800 MHz version. For the HHP the 900 MHz and 1800 MHz SAR liquids were used, and for the FBP the 1800 MHz liquid and the salt/water solution were used. The salt/water solution is specified by ETSI [9] (1.5 g NaCl per liter of distilled water). Recipes for both of the SAR liquids are given by Schmid & Partners [10].

In addition to the measurements in the GSM network, a number of measurements were also made in the anechoic chamber where the influence from the environment is eliminated. For this a GSM system simulator was used which acts as a real base station which is able to communicate with the handset being measured. The system simulator is controlled by a computer which may be used to, *e.g.*, command the handset to transmit with maximum power on a certain frequency. By combining the program for controlling the system simulator with a device which is able to rotate the handset along two axes in the anechoic chamber it is possible to measure complete spherical radiation patterns. The measurements were done in a 10° by 10° grid and are dual-polarized. By integration the total radiated power is computed from the spherical radiation pattern.

The anechoic chamber measurements were made for all four handsets using the head phantom described above, except that no hand was included in this case. Instead, the handset was fixed on the head in a similar position as with the hand. All three liquid types described above were used in these UL measurements at the center of the GSM-900 and GSM-1800 bands using frequencies of 902 MHz and 1747 MHz, respectively.

3. Measurement Processing

For each received MR an instantaneous link loss is computed using the RxLev and transmit power levels. The mean value of all the instantaneous link losses measured during each call is then used as a measure of the link quality for the particular handset, phantom type, *etc.*

The main interest in the current work is to investigate if the liquid type has any influence on the link loss. The HHP and the FBP are each measured using two kinds of liquids, thus allowing an isolated study of the changes introduced in the link loss when anything but the liquid is kept the same. The following only considers the difference in the mean link loss obtained with the two types of tissue simulating liquid. The absolute values of the body loss for the phantoms are investigated further in [11].

In the following measures of the form $\hat{\mu}_x - \hat{\mu}_y$ are used, where $\hat{\mu}_x = \sum_{i=1}^{N} x_i/N$ is an estimate of the true mean, μ_x, of the mean link loss for N measurements $x_1, x_2, \ldots, x_N$. Similarly $\hat{\mu}_y$ is an estimate of the mean value of the y, where M samples are used. The $100(1-\alpha)\%$ two-sided confidence interval for the estimated difference $\hat{\mu}_x - \hat{\mu}_y$ is given by $[\hat{\mu}_x - \hat{\mu}_y - S; \hat{\mu}_x - \hat{\mu}_y + S]$ where [12]

$$S = t_{\alpha/2,N+M-2} \times \left[\left(\frac{1}{N} + \frac{1}{M} \right) \left(\frac{(N-1)\hat{\sigma}_x^2 + (M-1)\hat{\sigma}_y^2}{N+M-2} \right) \right]^{1/2} \tag{1}$$

and $t_{\alpha,N}$ is the critical value of the t-distribution with N degrees of freedom at the critical level α. Eq. (1) assumes that the variance σ_x^2 of x equals the variance σ_y^2 of y, and furthermore that both x and y are Gaussian distributed. $\hat{\sigma}_x^2$ and $\hat{\sigma}_y^2$ are the variances estimated from the N and M measurements of x and y, respectively. The actual number of measurements used in the estimation may be less than 5 (or 4 for the 900 MHz liquid), due to lack of network capacity, errors by the people carrying out the measurements, *etc.* Also, some of the planned measurements were not carried out, due to lack of time.

While all the tested handsets are dual-band, it was found from the actual call traces that on the 2nd floor the

	Up-link		Down-link	
Pos.	Bse	2nd	Bse	2nd
α	0.1	-0.3	-1.1	-0.4
β	0.4	-0.9	-2.9	0.1
γ	0.8	-0.4	-2.2	-0.6
Mean	0.4	-0.5	-2.1	-0.3

Table 1: Differences in link loss for the two liquids, in dB and averaged over handsets for the FBP.

	Up-link		Down-link	
Handset	Bse	2nd	Bse	2nd
A	-0.9	-0.5	-3.0	-0.3
B	0.4	-0.8	-1.4	-0.2
C	0.7	-0.4	-1.4	-0.4
D	2.0	-0.4	-2.0	-0.4

Table 2: Differences in link loss for the two liquids, in dB and averaged over positions for the FBP.

1800 MHz band is used exclusively while at least 95% of each call on the basement floor is using the 900 MHz band.

4. Results

4.1. Full Body Phantom

Figure 3 shows the difference in the mean link loss for the two liquids tested in the FBP, *i.e.*, the salt/water and the 1800 MHz liquid. The differences are computed by subtracting the results for the 1800 MHz liquid from the salt/water results. Also shown in the figure are the confidence intervals associated with each mean difference.

A number of the difference estimates have larger confidence intervals than most of the estimates. Of the total 42 measures 5 have a two-sided confidence interval larger than 3 dB. Common for these cases is that the total number of measurements used to compute the mean values is only 4–6, usually because only one measurement was successful for the salt/water liquid. The remaining estimates are all computed using at least 7 measurements, except one (D/β/Bse/DL) which has an confidence interval smaller than 3 dB. The median total number of measurements is 9.

The results for position β and γ can be expected to be similar since in both positions the display is away from the phantom. The only difference is height and orientation with respect to the direction of motion. Indeed, the obtained results have similarities regarding the relative results for the four handsets. For example, for both the β and γ positions for 2nd/DL handset C has the most negative value among the four. The similarities are more evident on the basement floor where handset A has the most negative value for both UL and DL.

Table 1 shows differences averaged over handsets. All the values are less than one dB, except for the Bse/DL combination where significant differences were found. The β- and γ-positions have almost equally high negative values, where the α-position has a value similar to those obtained for other floor/direction combinations. This compares well with the fact that for the α-position the handsets are mounted with the display towards the phantom, and hence the antennas are pointing away from the phantom.

From Figure 3 the UL results on the 2nd floor generally seem to be lower than zero, where the basement floor results are closer to zero or are slightly positive. For the DL, the results for the basement floor are generally negative and the 2nd floors results seem to be close to zero. Average values for the differences are shown in Table 1 (the ‘Mean’ row). From these numbers it may be concluded that the differences are negligible except for the basement/DL combination where the 1800 MHz liquid results in a larger link loss than the salt/water solution.

Table 2 shows the differences averaged over the three positions. For the 2nd floor the values are nearly the same, with a maximum difference among the handsets of 0.4 dB and 0.2 dB for the UL and DL directions, respectively.

For the basement floor, the handsets behave more unequally for the two liquid types. The maximum differences among handsets are here 2.9 dB for the UL and 1.6 dB for the DL. However, it should be noted that on the basement floor also the confidence intervals are rather large, especially for handsets A and D (see Figure 3).

It is worth noting from Table 2 that except for handset A in the UL-direction on the basement floor, the values all have the same sign when the different handsets are used for the same floor/direction combination.

4.2. Head & Hand Phantom

The confidence intervals are generally larger for the HHP results than for the FBP results. The larger uncertainty is partly due to a smaller number of measurements involved (total number median of 7), and partly due to a larger variance in the link loss measurements. The latter can be explained as the results of the measurement procedure involving more sources of changes when compared to the measurements with the FBP. All the estimates have two-sided 95% confidence intervals less than 5 dB, except 4 of the in total 28 estimates where only one measurement for the 1800 MHz liquid is included. Most estimates (21 of the 28) have confidence intervals in the range 1.5–3.9 dB.

All the mean values obtained with the HHP are shown in Table 3 which is computed by subtracting the results for the 1800 MHz liquid from the 900 MHz liquid results. For handset A all values seem to be close to zero, except perhaps for the basement/UL combination which is about -1 dB for both the α- and the β-position.

Significant differences of around 6 dB were obtained

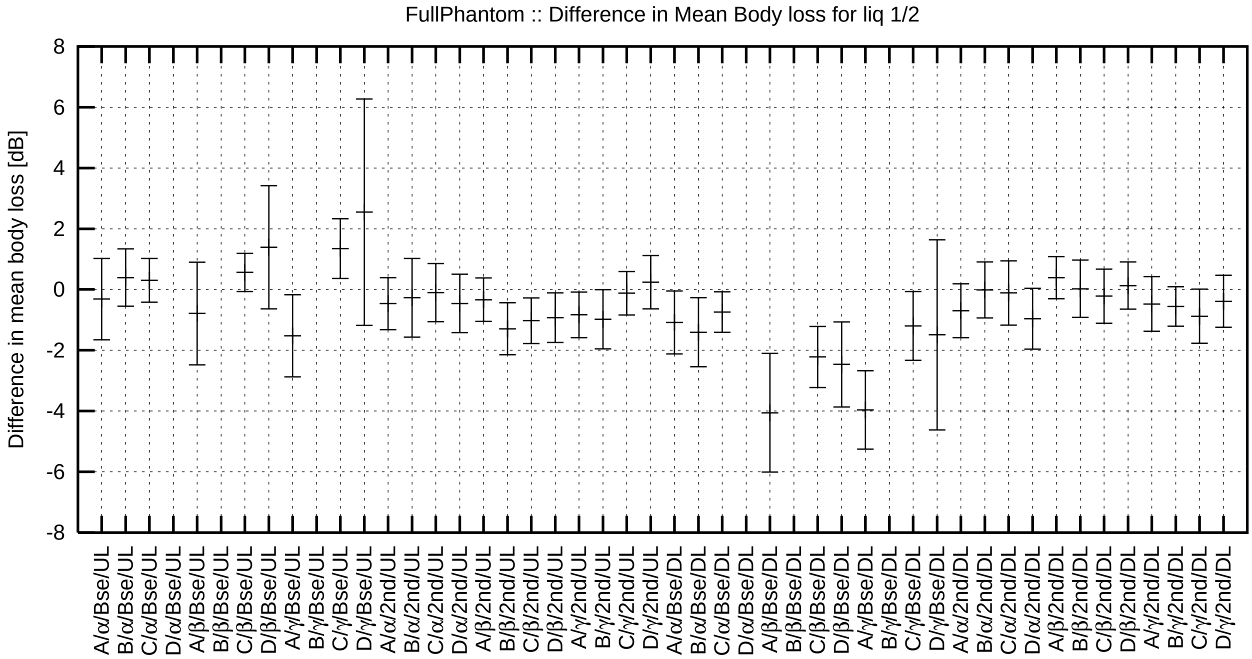

Figure 3: Differences in link loss for the two liquids and the FBP. The error bars show the 95% confidence intervals. The x-axis labels are given in the form: handset/position/level/direction.

Dir.	Floor	Pos.	Handset A	Handset B	Handset C	Handset D
UL	Bse	α	-1.0	6.6	0.6	1.8
		β	-1.3	0.7	-1.2	-
	2nd	α	0.4	-1.6	-1.9	0.3
		β	-0.0	-1.1	3.9	-
DL	Bse	α	-0.4	5.7	0.8	0.8
		β	-0.1	0.1	0.1	-
	2nd	α	0.1	-1.7	-1.8	0.8
		β	-0.6	-1.2	2.3	-

Table 3: Average body loss differences in dB for the HHP.

for handset B in the α-position for both the UL and DL directions on the basement floor. For the 2nd floor the difference is about -1.4 dB on average.

For handset C there seems to be relatively large differences in using the α- and β-positions on the 2nd floor for both the UL and DL directions, which also seems to have similar absolute values. On the basement floor there are also some differences but both the UL and DL values have large confidence intervals.

No measurements were made with Handset D in the β-position and the 900 MHz liquid. In the α-position all combinations of floor and direction have values less than 1 dB, except the UL direction on the basement with a value of 1.8 dB. However, this value has a confidence interval of almost 5 dB.

Considering the confidence interval sizes mentioned above, most of the values in Table 3 are small and therefore probably can be considered as insignificant, *i.e.*, there is no difference in using the two types of liquids.

However, there are a few of the values that cannot be considered close to zero. For example the results of the α-position for handset B on the basement floor UL shows that the 900 MHz liquid results in a link loss 6.6 dB higher than the 1800 MHz liquid. This difference seems strange when comparing to results with the other handsets and therefore the measurement procedures were searched for possible errors sources. The measurements with the 1800 MHz liquid were made 10 days after those with the 900 MHz liquid and hence differences in the procedure could not be ruled out. A considerable amount of photographs were made during the measurement campaign, among which are photographs of how all the handsets were mounted behind the hand on the head phantom. From the photographs of the two measurement series it was found that in both cases the thumb of the phantom hand is stretched towards the top of the handset. During the measurements with the 900 MHz liquid the thumb is bend slightly so it touches the back of the handset in the part were the internal antenna is located. With the 1800 MHz liquid the thumb is bend slightly towards the front of the handset and the head, and it is thus not touching the antenna. It is known that the a hand/finger located close to the antenna will increase the absorption by several dB compared to when the fingers are not close [8]. This is therefore the most likely explanation of the larger link loss found in the measurements obtained with the 900 MHz liquid.

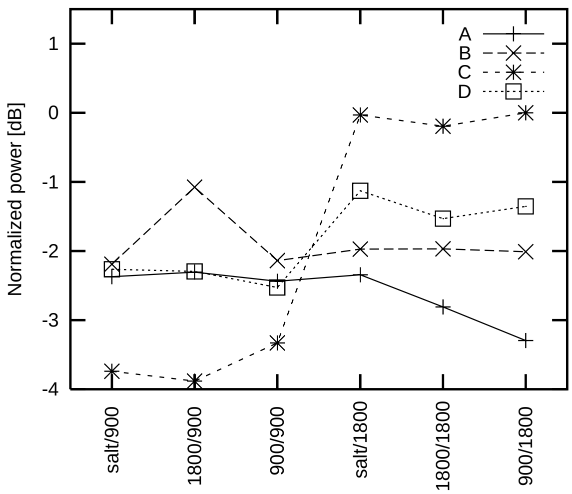

Figure 4: Normalized transmitted power measured in the anechoic chamber. The x-axis labels are shown as liquid/frequency band.

4.3. Anechoic Chamber Measurements

All the results presented so far were obtained using the GSM network. The total power received by the handsets depend on the signal distribution in the mobile environment and hence the assessment of the liquids in principle depends on the environment. In order to exclude the influence of the environment, the handsets and the phantom were also measured in the anechoic chamber.

Figure 4 shows the UL received power normalized to the maximum power. The results for the different liquid types are almost identical. Depending on the handset, the maximum differences are 0.1–1.1 dB and 0.0–1.0 dB for the 900 MHz and 1800 MHz bands, respectively.

Another way to characterize the similarities is to use the correlation coefficient of the spherical power distributions, in dB, obtained with the different liquids. Except for 3 correlation values in the range 0.87–0.89, all the values are in the range 0.92–1.00, showing that the radiation patterns are very similar for the different liquids.

5. Conclusion

The influence of liquid type on the link loss was investigated using two kinds of phantoms, where the difference in link loss obtained for the various liquid types was used as a measure. For the full body phantom it was found that most of the values were within ± 1 dB which is comparable to the confidence intervals of the measurements. As a special case, the combination of down-link and the basement floor the 1800 MHz SAR liquid resulted in a larger link loss than the salt/water liquid, where it should be noted that on the basement floor the handsets use the 900 MHz band. The difference found was 1–3 dB depending on the position and the handset, with handset A and D possibly mostly affected.

For the head/hand phantom, most of the differences found are small, within ± 2 dB. Considering the measurement uncertainty it is generally believed that the difference in using the two liquid types is small. However, a few differences of up to 6.6 dB were found. From photographs it was found that these can probably be attributed to errors in the measurement procedure.

Furthermore, all handsets were measured in the anechoic chamber where the influence of the environment is eliminated. From these measurements it was found that the changes in the transmitted power due to the liquid type were less than 1.1 dB.

6. Acknowledgments

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7. References

[1] Tokio Taga. Analysis for mean effective gain of mobile antennas in land mobile radio environments. *IEEE Transactions on Vehicular Technology*, 39(2):117–131, May 1990.

[2] Jørgen Bach Andersen and Flemming Hansen. Antennas for VHF/UHF personal radio: A theoretical and experimental study of characteristics and performance. *IEEE Transactions on Vehicular Technology*, 26(4):349–357, November 1977.

[3] Luis M. Correia, editor. *Wireless Flexible Personalised Communications. COST 259: European Co-operation in Mobile Radio Research*. Wiley, 2001.

[4] Gert F. Pedersen, Jesper Ø. Nielsen, Kim Olesen, and Istvan Z. Kovacs. Measured variation in performance of handheld antennas for a large number of test persons. In *48th Vehicular Technology Conference, VTC '98*, pages 505–509. IEEE, May 1998.

[5] Hiroyuki Arai, Nobuhiro Igi, and Hirokazu Hanaoka. Antenna-gain measurement of handheld terminals at 900 MHz. *IEEE Transactions on Vehicular Technology*, 46(3):537–543, August 1997.

[6] Jesper Ødum Nielsen, Gert Frølund Pedersen, and Christophe Solis. In-network evaluation of mobile handset performance. In *Vehicular Technology Conference (VTC'2000 Fall)*. IEEE, September 2000.

[7] Jesper Ø. Nielsen, Gert F. Pedersen, Kim Olesen, and Istvan Z. Kovács. Statistics of measured body loss for mobile phones. *To appear in the August issue of IEEE Transactions on Antennas and Propagation*, 2001.

[8] Gert Frølund Pedersen, Mathieu Tartiere, and Mikael B. Knudsen. Radiation efficiency of handheld phones. In *50th Vehicular Technology Conference, VTC'2000*. IEEE, May 2000.

[9] European Telecommunications Standards Institute (ETSI). ETS 300 341.

[10] Schmid & Partner, http://www.speag.com/. Generic torso phantom, v.3.6.

[11] Jesper Ødum Nielsen and Gert Frølund Pedersen. In-network evaluation of body carried mobile terminal performance. To be published in the proceedings of The 12th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2001), September 2001.

[12] Sheldon M. Ross. *Introduction to Probability and Statistics for Engineers and Scientists*. John Wiley & Sons, 1987.